

Status of the KIMS experiment

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Center for Underground Physics
at Institute for Basic Science, Korea



KIMS (Korea Invisible Mass Search)

*Center for Underground Physics at
Institute for Basic Science*

2010

2015

2020

Time (year)

KIMS CsI(Tl) crystals

KIMS NaI(Tl)

KIMS-LT

- Direct detection programs of Dark Matter using scintillation crystals in Korea
- 2005-Present : Dark Matter search with CsI(Tl) crystals (**KIMS-CsI**)
- 2013-Present : **Development for NaI(Tl)** crystal selection
- 2016-2020 : Dark Matter runs with NaI(Tl) crystal (**KIMS-NaI**)
- 2017-2025 : Dark Matter experiment at low temperature (**KIMS-LT**)

*focus for
this talk*

YangYang Laboratory (Y2L)

Upper Dam

Depth 700m

A5 Tunnel KIMS-NaI

Power Plant

A6 Tunnel KIMS-Csl

Access by car to the lab (2 km)

Lower Dam

Situated at YangYang Pumped Storage Power Plant



YangYang Laboratory (Y2L)

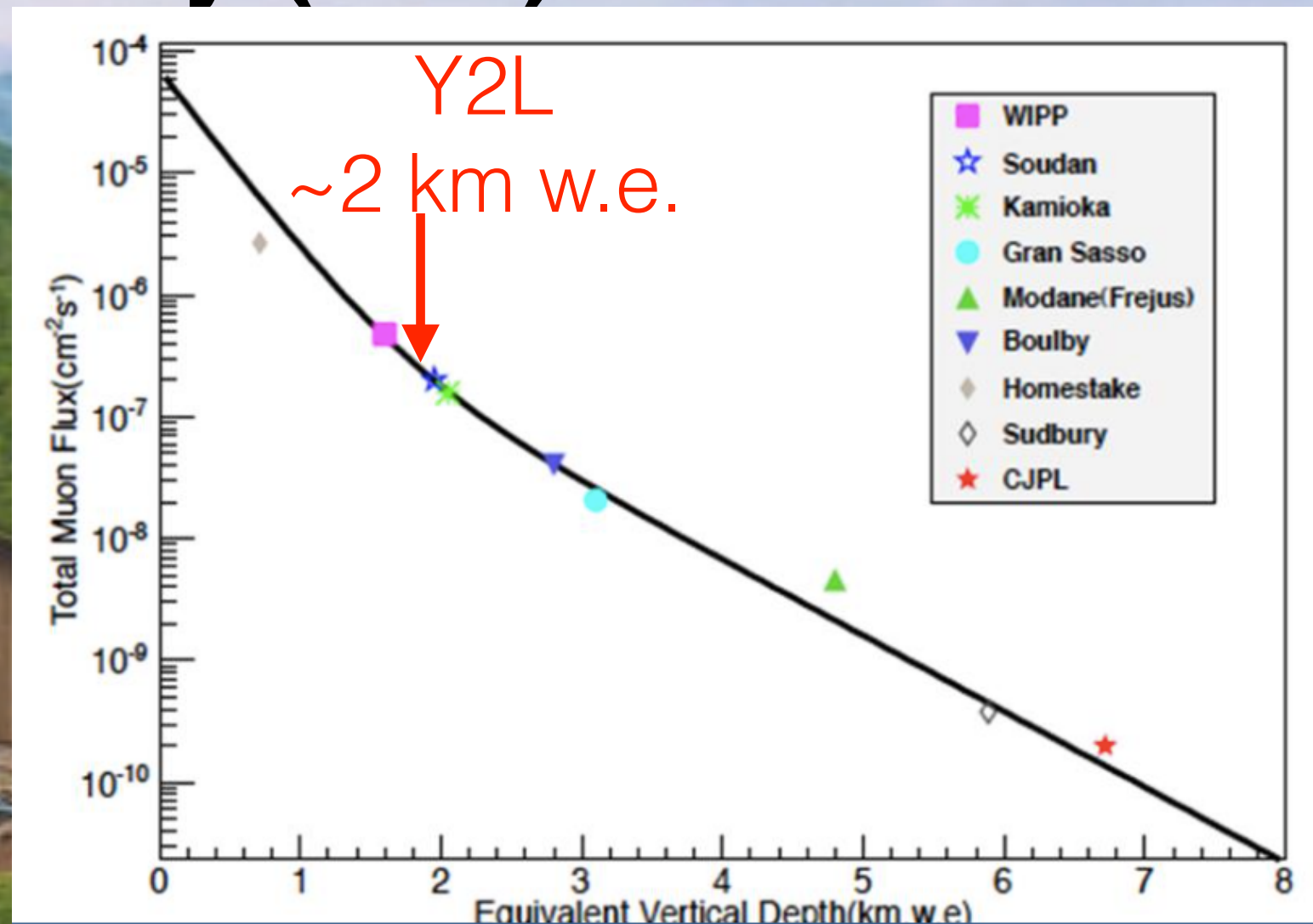
Upper Dam

Depth
700m



A6 Tunnel
KIMS-CsI

Situated at YangYang Pumped Storage Power Plant



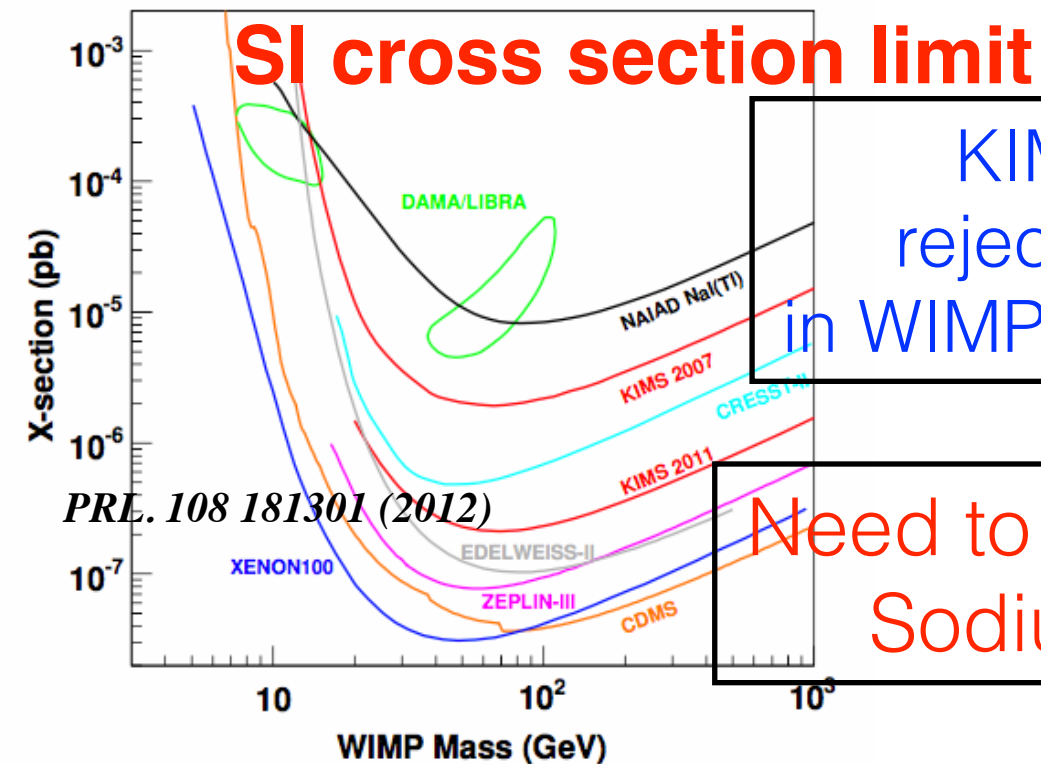
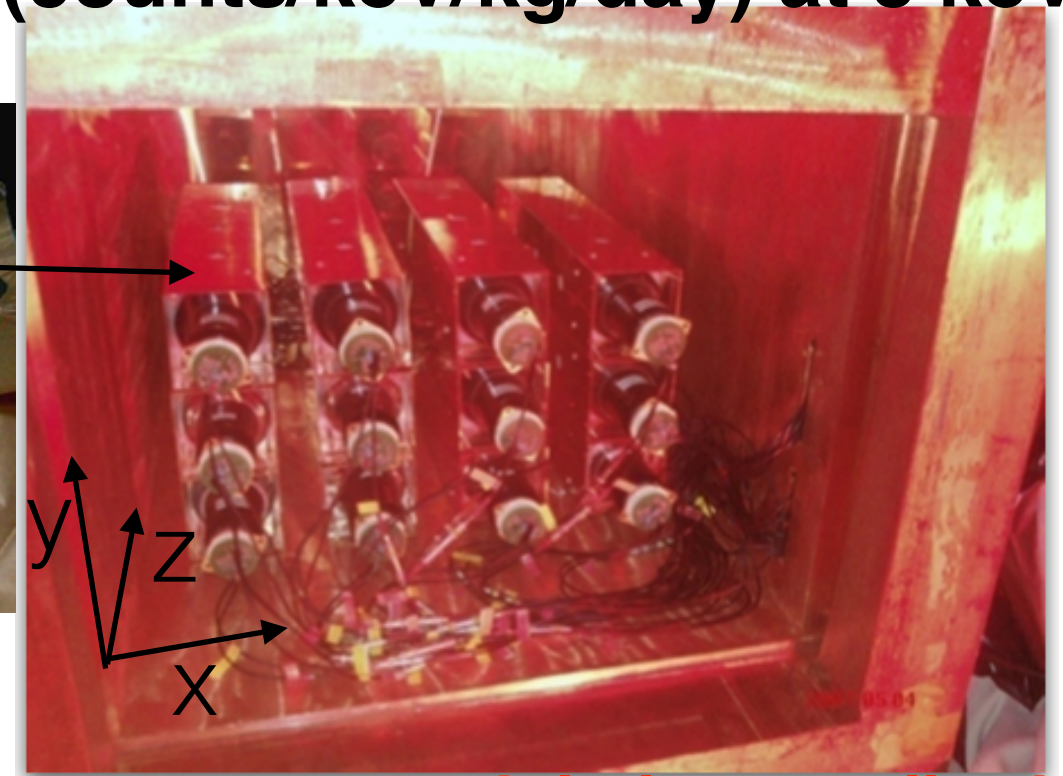
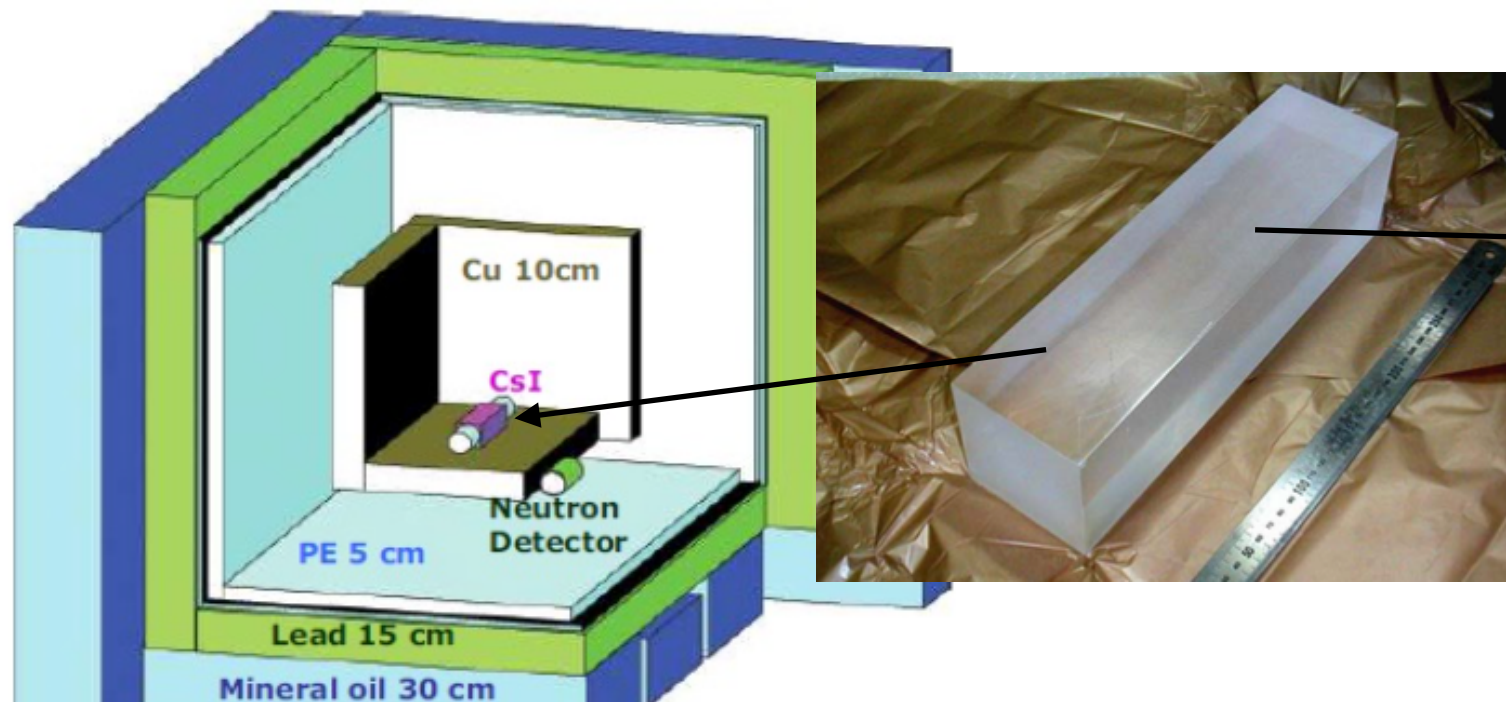
Access by car to the lab (2 km)

Lower Dam

KIMS-CsI

12 CsI(Tl) 8.7 kg crystals (103 kg total)

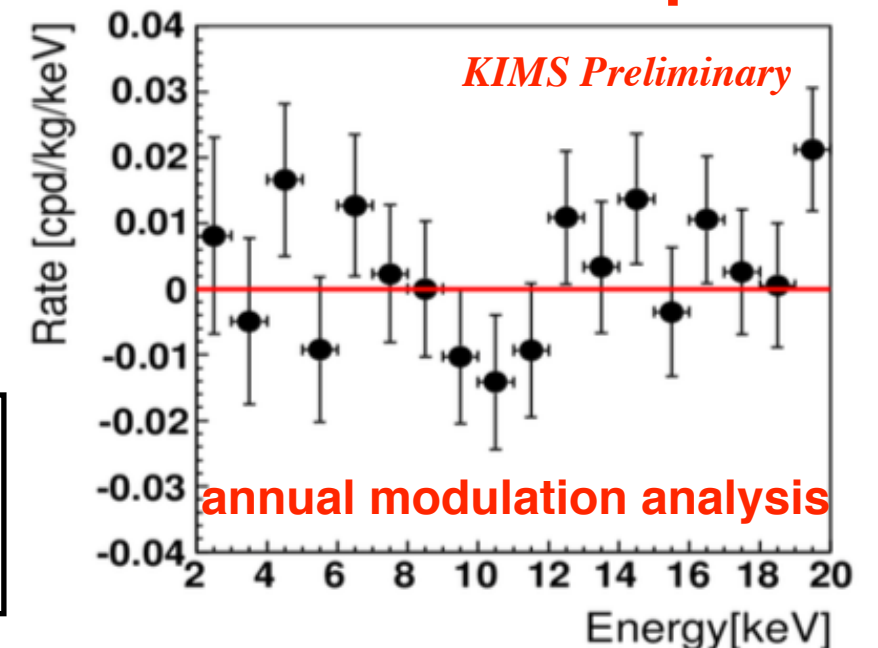
Background level achieved at ~ 3 dru (counts/keV/kg/day) at 3 keV



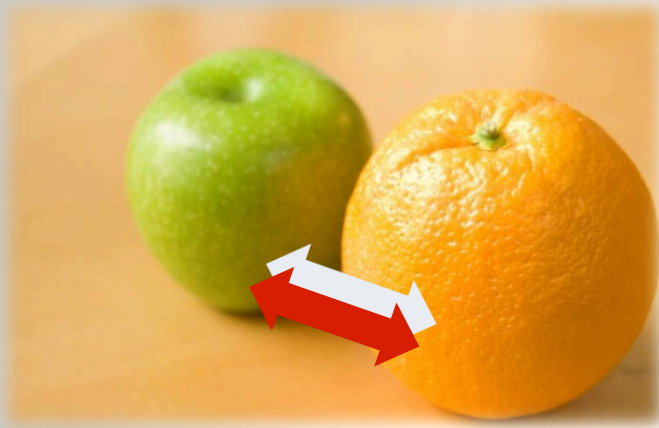
KIMS-CsI results
rejects DAMA signal
in WIMP-Iodine interactions

Need to investigate WIMP-
Sodium interactions

modulation amplitude



DAMA/LIBRA at NDM15 in Finland (last week)



About interpretation

See e.g.: Riv.N.Cim.26 n.1(2003)1, IJMPD13(2004)2127, EPJC47(2006)263, IJMPA21(2006)1445, EPJC56(2008)333, PRD84(2011)055014, JMPA28(2013)1330022

...models...

- Which particle?
- Which interaction coupling?
- Which Form Factors for each target-material?
- Which Spin Factor?
- Which nuclear model framework?
- Which scaling law?
- Which halo model, profile and related parameters?
- Streams?
- ...

...and experimental aspects...

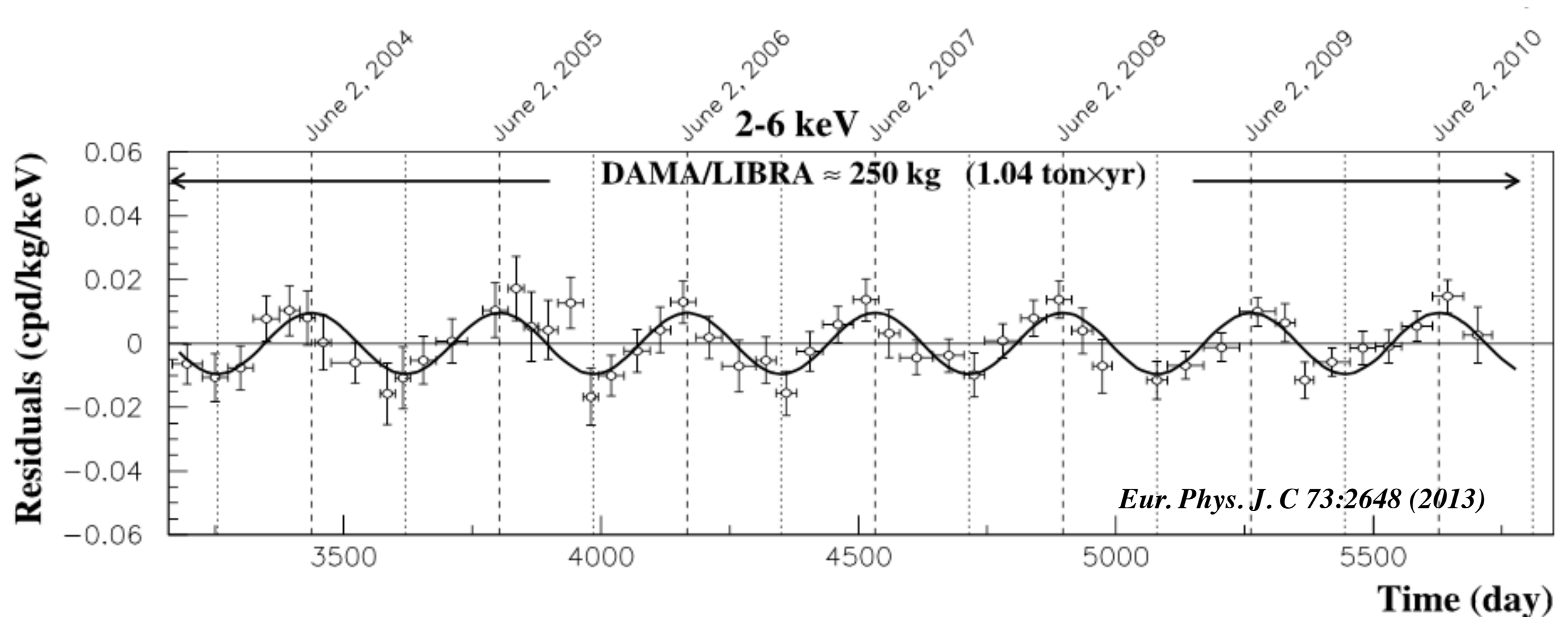
- Exposures
- Energy threshold
- Detector response (phe/keV)
- Energy scale and energy resolution
- Calibrations
- Stability of all the operating conditions.
- Selections of detectors and of data.
- Subtraction/rejection procedures and stability in time of all the selected windows and related quantities
- Efficiencies
- Definition of fiducial volume and non-uniformity
- Quenching factors, channeling
- ...

Uncertainty in experimental parameters, as well as necessary assumptions on various related astrophysical, nuclear and particle-physics aspects, affect all the results at various extent, both in terms of exclusion plots and in terms of allowed regions/volumes. Thus comparisons with a fixed set of assumptions and parameters' values are intrinsically strongly uncertain.

No experiment can be directly compared in model independent way with DAMA

??

Motivation for KIMS-NaI



- Direct comparison to prove or dispute DAMA/LIBRA claims using NaI crystal.

Nal(Tl) Dark Matter Experiments

- **KIMS-Nal at YangYang Lab in Korea**
 - Six crystals (Alpha Spectra Inc. & Beijing Hamamatsu) have been tested
- **ANAIS at Canfranc Lab in Spain**
 - Two crystal (Alpha Spectra Inc.) detector (total 25kg) operational (since Oct, 2012)
- **DM-Ice at 2.5km depth South Pole ice**
 - Two crystals (total 17 kg) from NAIAD experiment (since June, 2011)
- **KamLAND-PICO, Japan**
 - 15cmX15cmX0.1cm scintillator, Pb210 reduction ~ 60 μ Bq/kg level
- **SABRE**
 - Independent crystal growth with RMD Inc. High light yield (~20PE/keV)

Requirement of KIMS-NaI

- Achieve ultra-low background and lower energy threshold than DAMA/LIBRA (~ 1 dru at 2 keV) using the similar NaI crystal detectors and test annual modulation signal.
- Requirement :
 - Background level **less than 1 dru (count/keV/kg/day) at 2 keV region.**
 - **200 kg X 3 years of data** would test the DAMA/LIBRA signals

Crystal Background Evaluation & Background Reduction

- **Nal(Tl) crystal internal background screening** : Estimate the internal background from data analyses.
 - K : Coincidence analysis with existing CsI crystal array.
 - U/Th/Pb : Time difference analyses with alpha events.
 - Cosmogenics : Coincidence analysis + Estimates from spectrum fit.
- **Liquid scintillator veto** : Reduces external backgrounds and residual internal backgrounds.
- **Purification of Nal(Tl) powder** : Develops Nal(Tl) powder purification techniques (verify with ICP-MS or several alpha detectors)

Six cylindrical NaI(Tl) crystals evaluated at Y2L

	NaI-001	NaI-002	NaI-003	NaI-004	NaI-005	NaI-006
Mass	8.3 kg	9.2 kg	3.4 kg	3.4 kg	9.2 kg	11.4 kg
Powder	AS	AS	SA-AG	SA-CG	AS[@]	SA-CG
Crystal	AS	AS	AS	AS	AS	BH
Arrival	2013.9	2014.1	2014.8	2014.8	2014.11	2014.12

AS = Alpha Spectra Inc (Denver, CO),

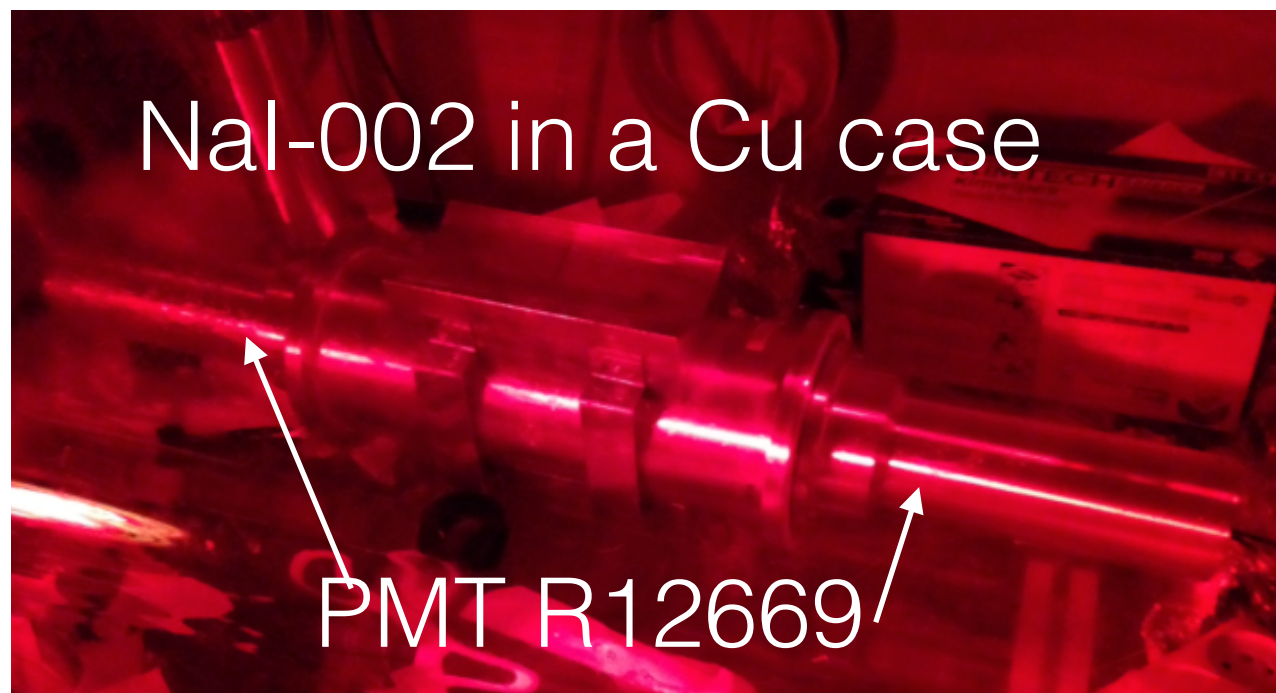
BH = Beijing Hamamatsu (China)

AS[@] = WIMP-grade (less Pb210)

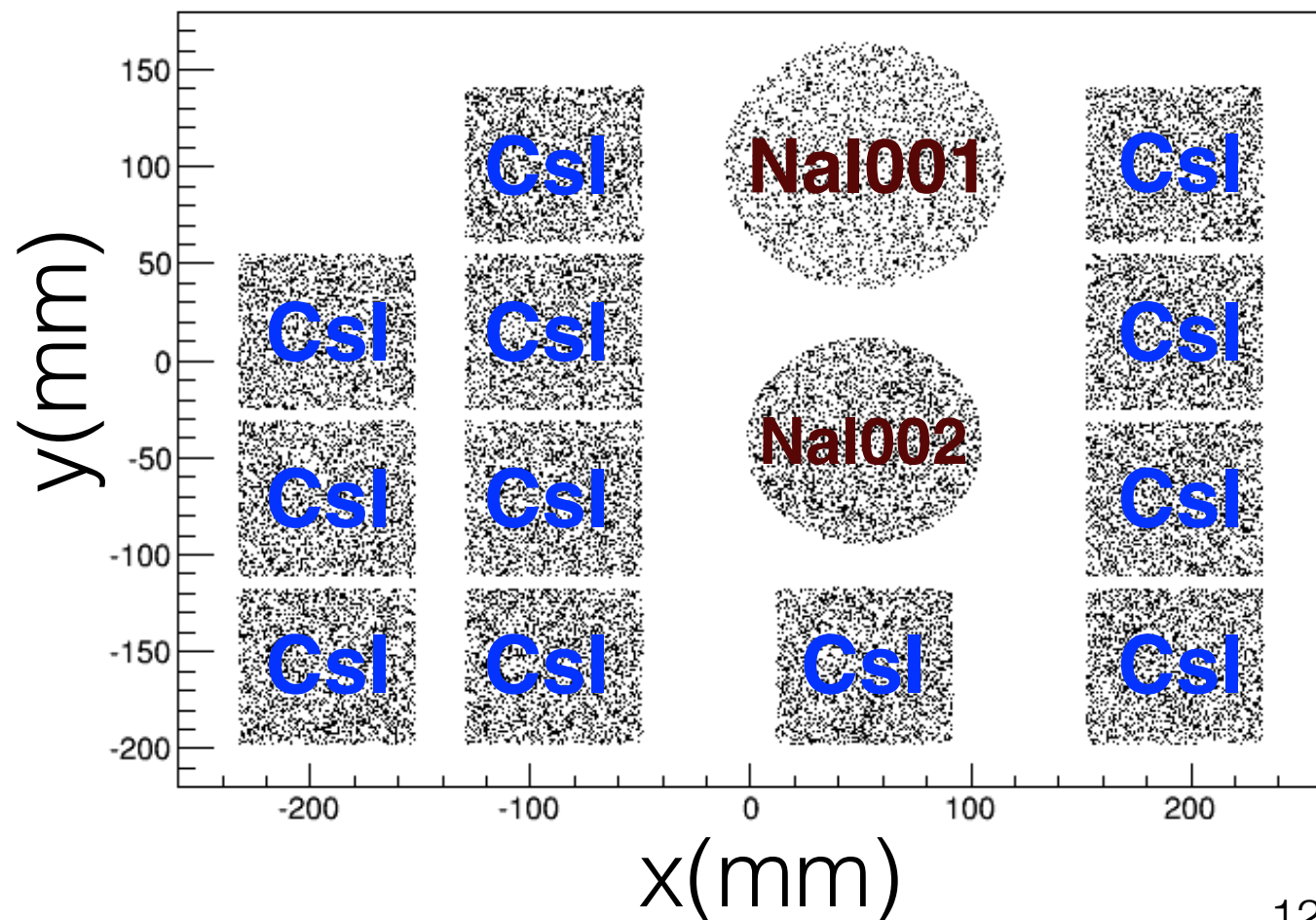
SA-AG = Sigma Aldrich, Astro-Grade (less K40)

SA-CG = Sigma Aldrich, Crystal-Grade

Crystal Screening Setup



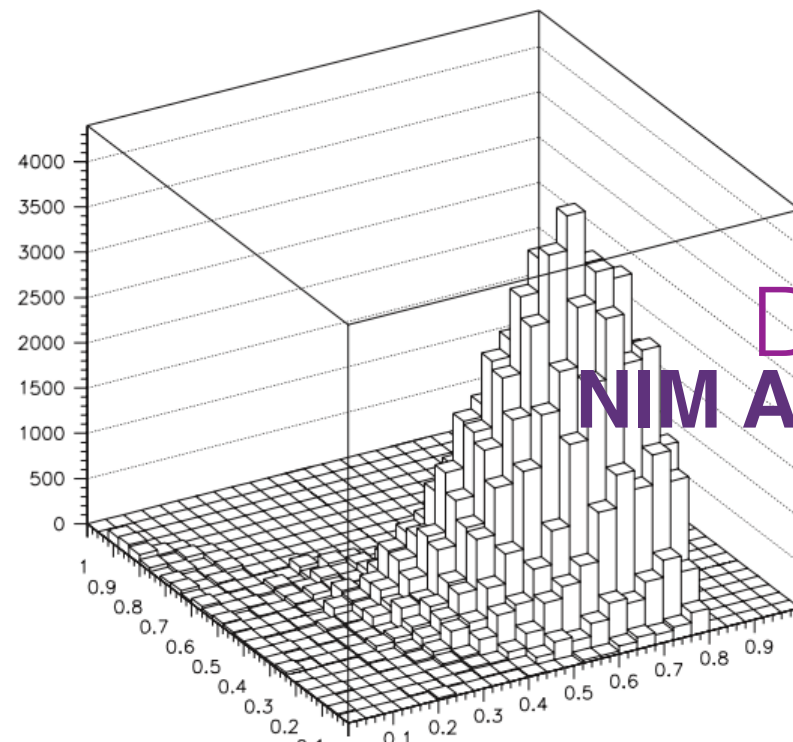
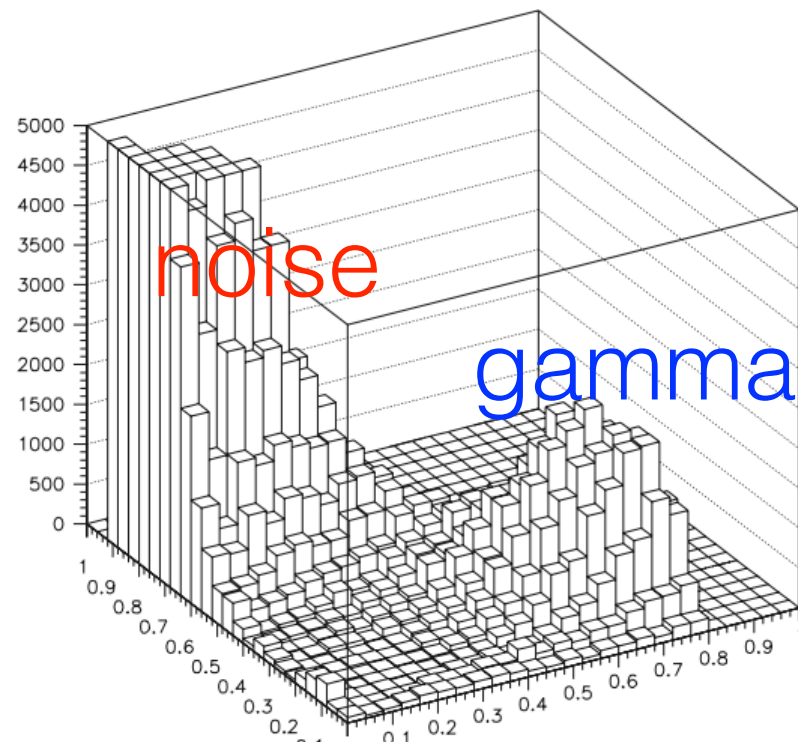
- Use existing CsI(Tl) array with upgraded PMTs
- PMT : Hamamatsu R12669
 - 35% Quantum Efficiency at 420 nm
 - High light yield :
~15photoelectron/keV
- Readout : 400 MHz FADC (Notice Korea Inc.)
- Trigger : 1 photoelectron/PMT within 100 ns



PMT Noise Background Reduction I

-fast event rejection

(events which register most of charge within first 50 ns)



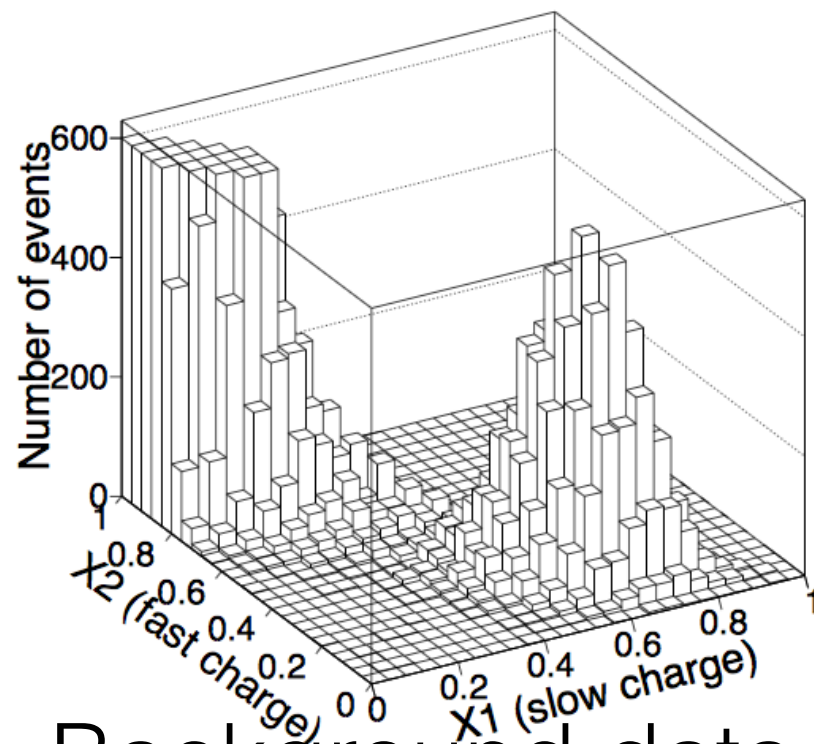
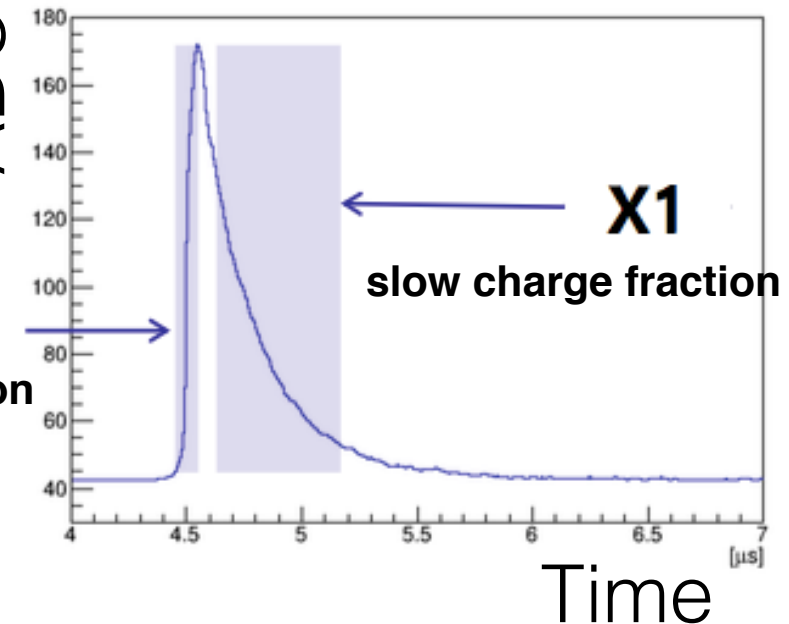
DAMA
NIM A 592 (2008)

Waveform

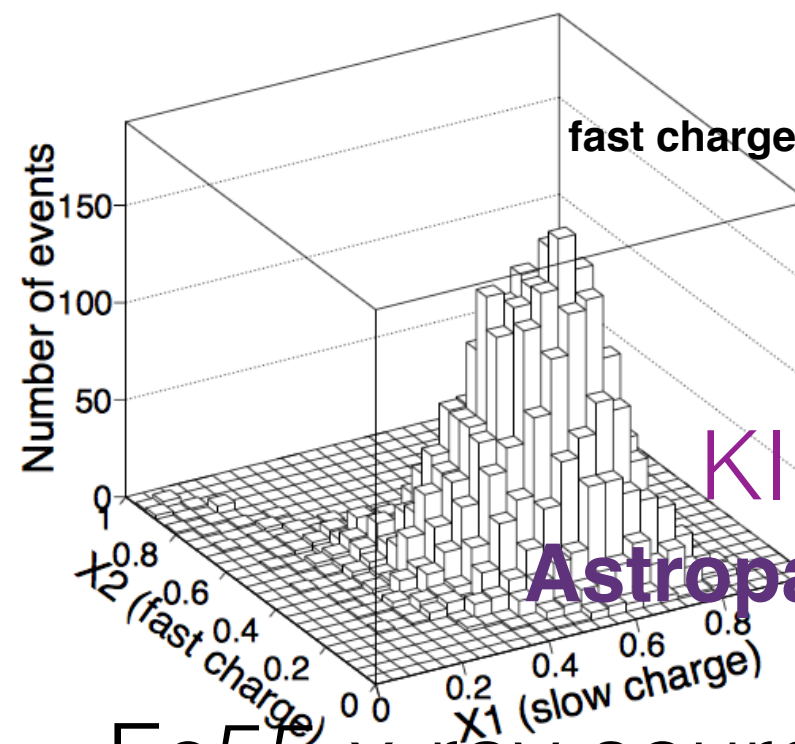
ADC

X2

fast charge fraction



Background data



Fe55 x-ray source (~6keV)

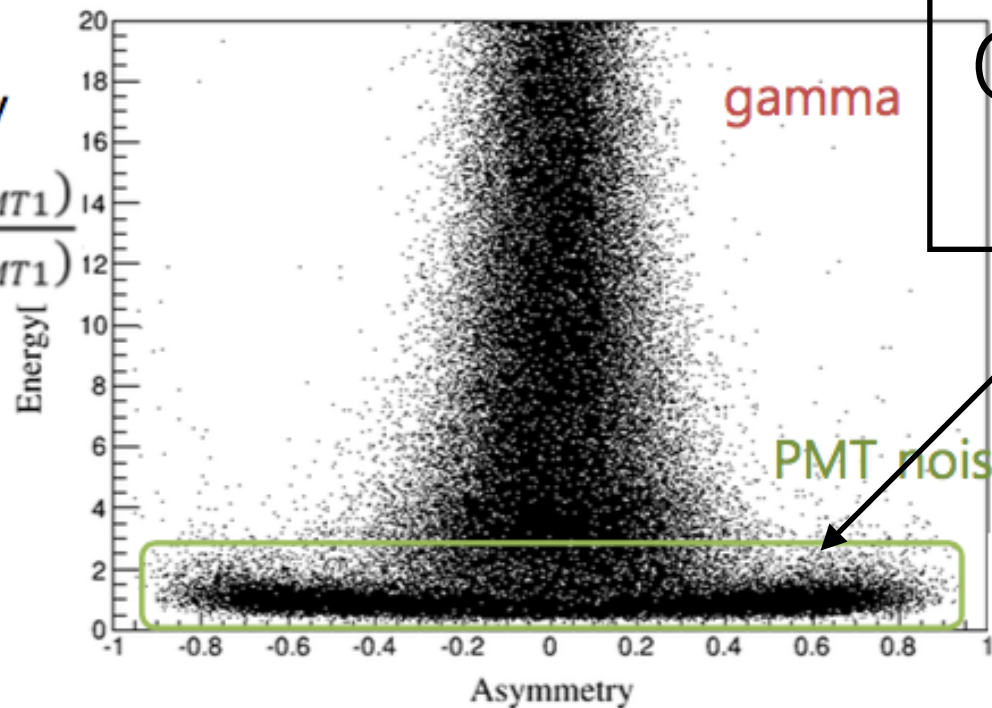
KIMS-NaI
Astroparticle Physics 62(2015)

PMT Background Reduction II

-More PMT noise cuts (not done in DAMA)

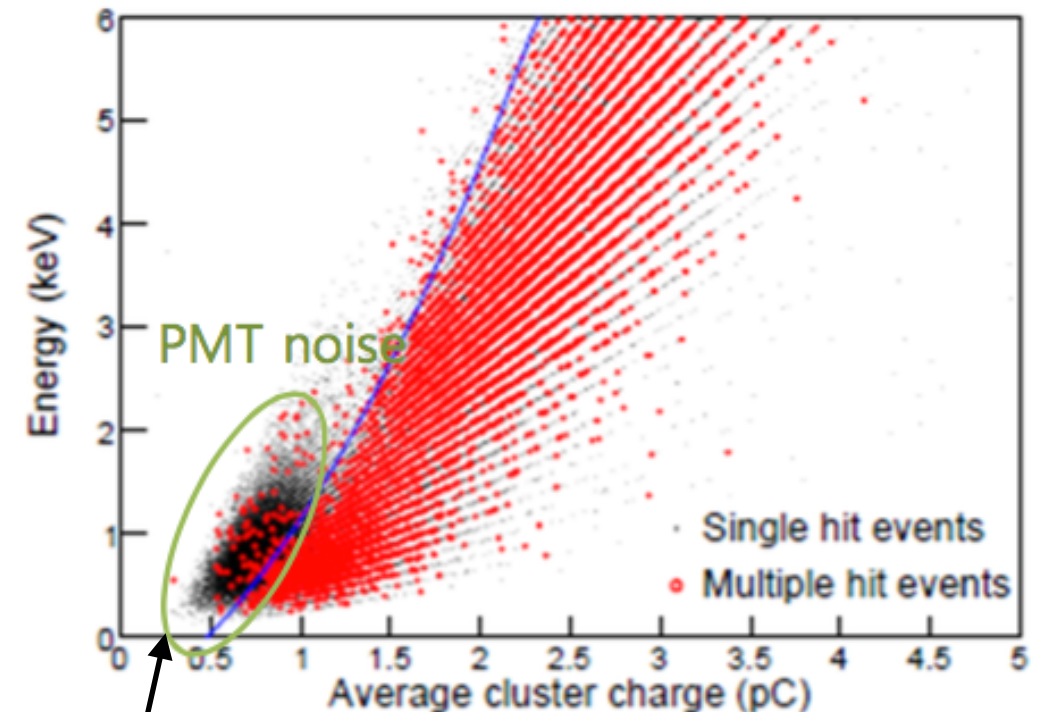
- Charge Asymmetry

$$Asymmetry = \frac{(Q_{PMT0} - Q_{PMT1})}{(Q_{PMT0} + Q_{PMT1})}$$



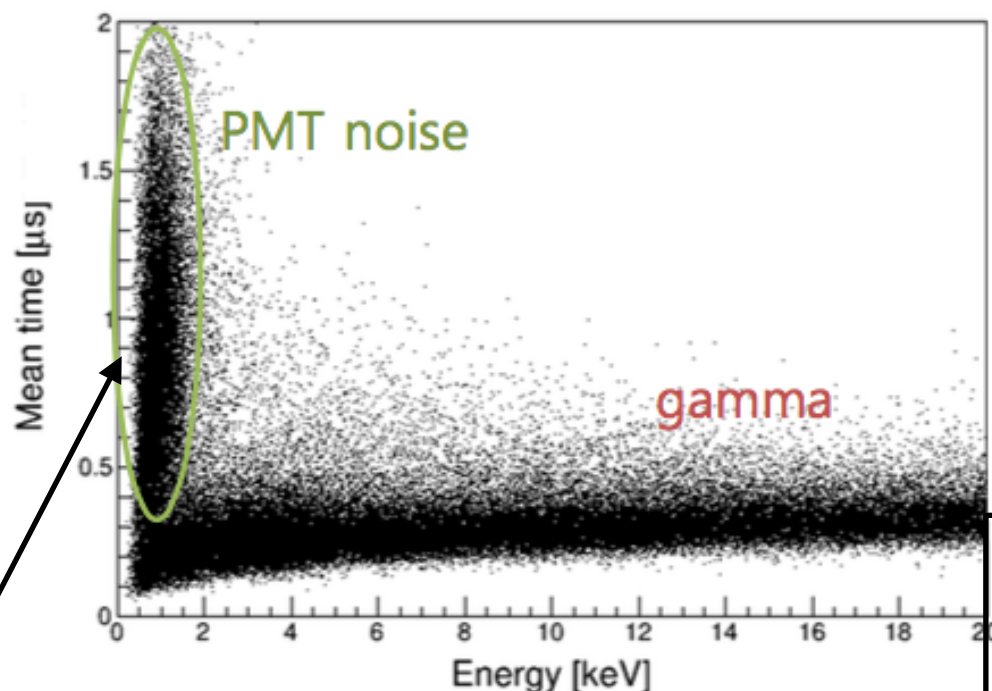
Only one PMT records most of light

- Average cluster charge



- Mean time

$$Mean\ time = \frac{\sum A_i \times t_i}{\sum t_i}$$

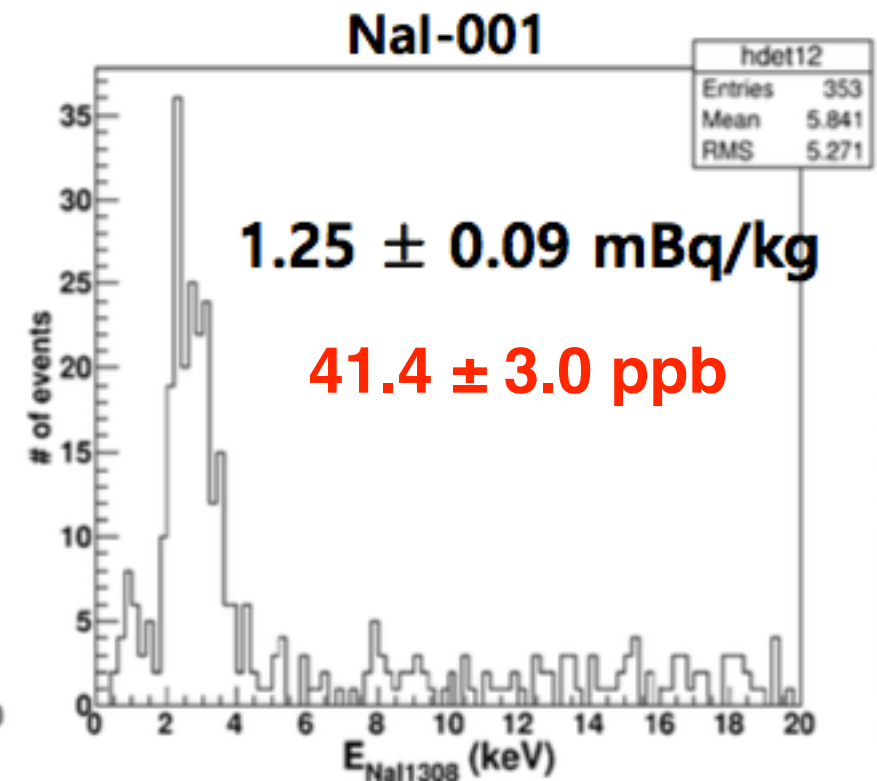
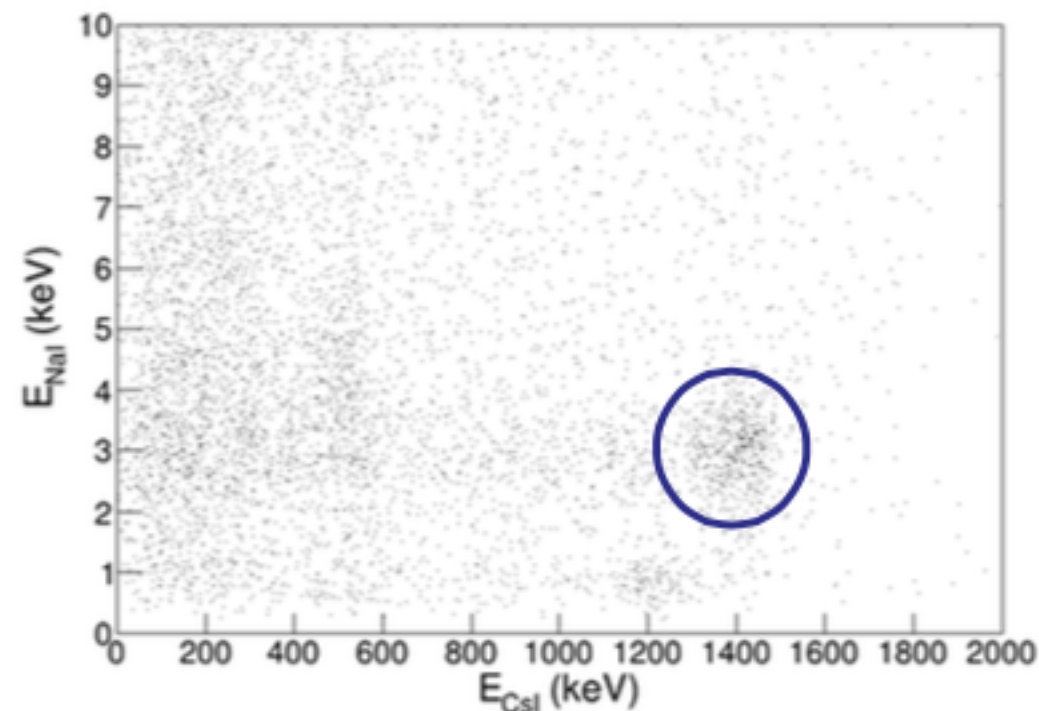
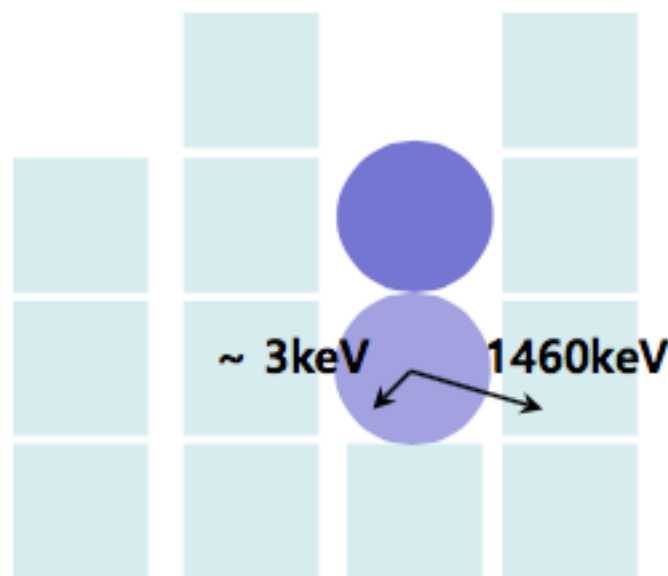


Low energy signal that is erroneously long decay time

SPEs distributed too uniformly over long time

Internal Crystal Background - K

CsI-NaI Coincidence Analysis



Selection Efficiency calculated from MC

DAMA K(ppb)=10~20 ppb

	NaI-001	NaI-002	NaI-003	NaI-004	NaI-005	NaI-006
K(ppb)	41.4±3.0	49.3±2.4	25.3±2.4	>110	40.1±4.2	>150

Internal Crystal Background - K

DAMA K(ppb)=10~20 ppb

	Nal-001	Nal-002	Nal-003	Nal-004	Nal-005	Nal-006
K(ppb)	41.4±3.0	49.3±2.4	25.3±2.4	>110	40.1±4.2	>150
K(powder)	?	?	25.1	~200	?	~200
Powder	AS	AS	SA-AG	SA-CG	AS [@]	SA-CG

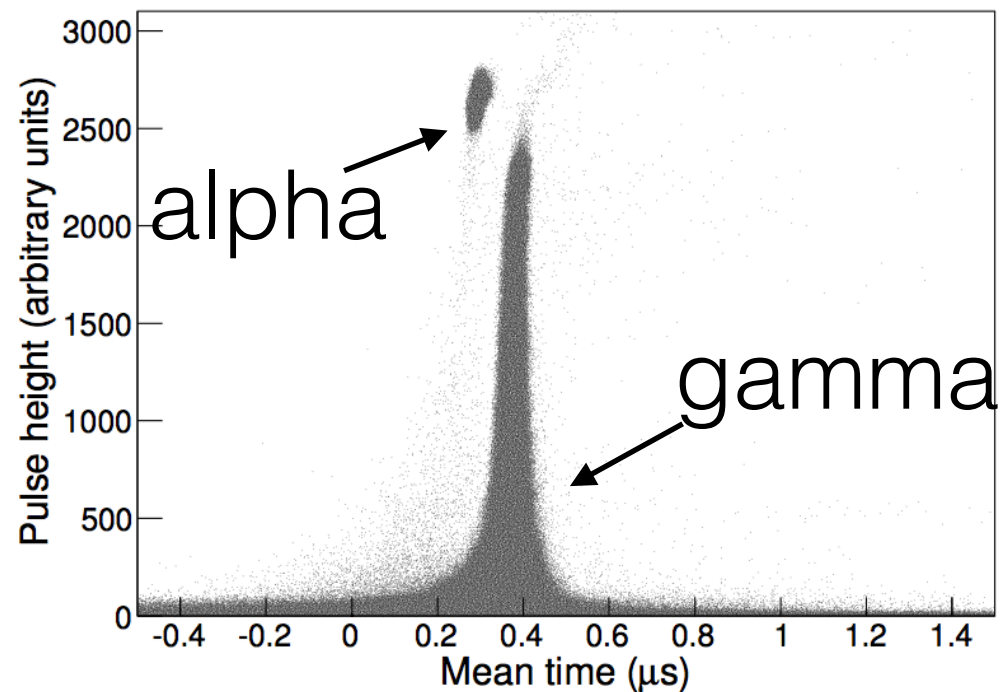
- K contamination is determined at powder level instead of crystal growth level.
- Powders from Alpha Spectra shows 40 ppb level K (Nal-001, 002, & 005)
- **Sigma Aldrich Astro-Grade** powder shows lower level of K at 25 ppb.
- A new crystal is being grown by using **Sigma Aldrich 10 ppb level** powder (ICP-MS measurement)
- R&D for K reduction in NaI(Tl) powder is on-going.

Internal Crystal Background (Alpha analysis)

DAMA $^{238}\text{U}(\text{mBq/kg})=0.009\sim0.13$

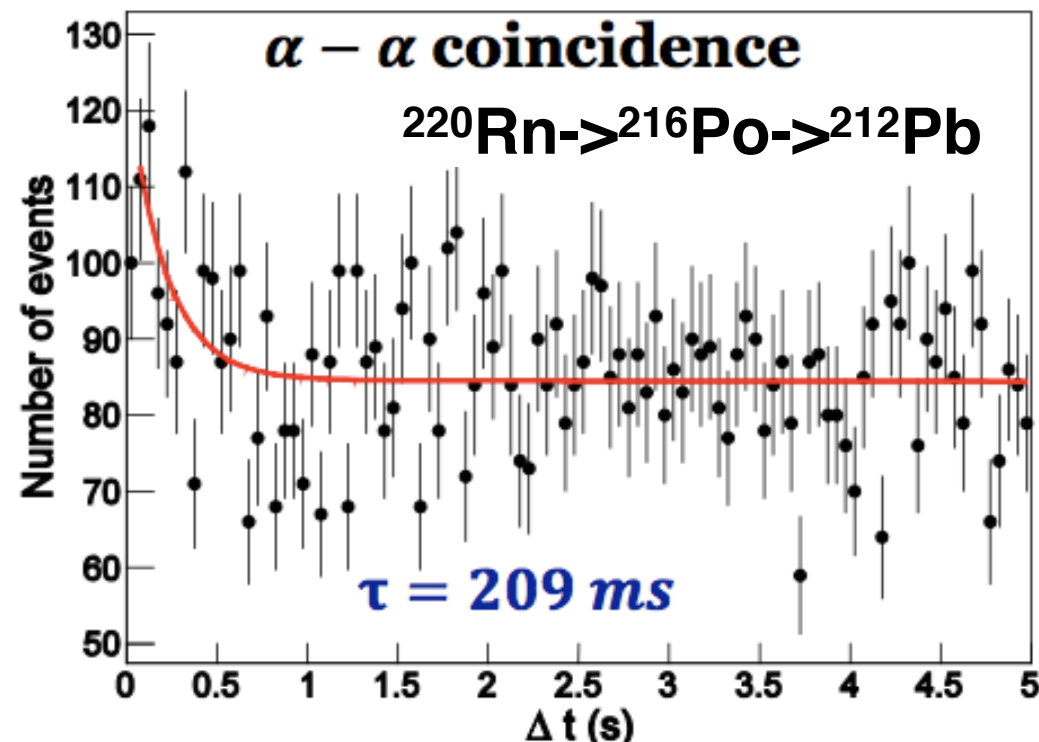
$^{232}\text{Th}(\text{mBq/kg})=0.002\sim0.03$

$^{210}\text{Pb}(\text{mBq/kg})=0.005\sim0.03$

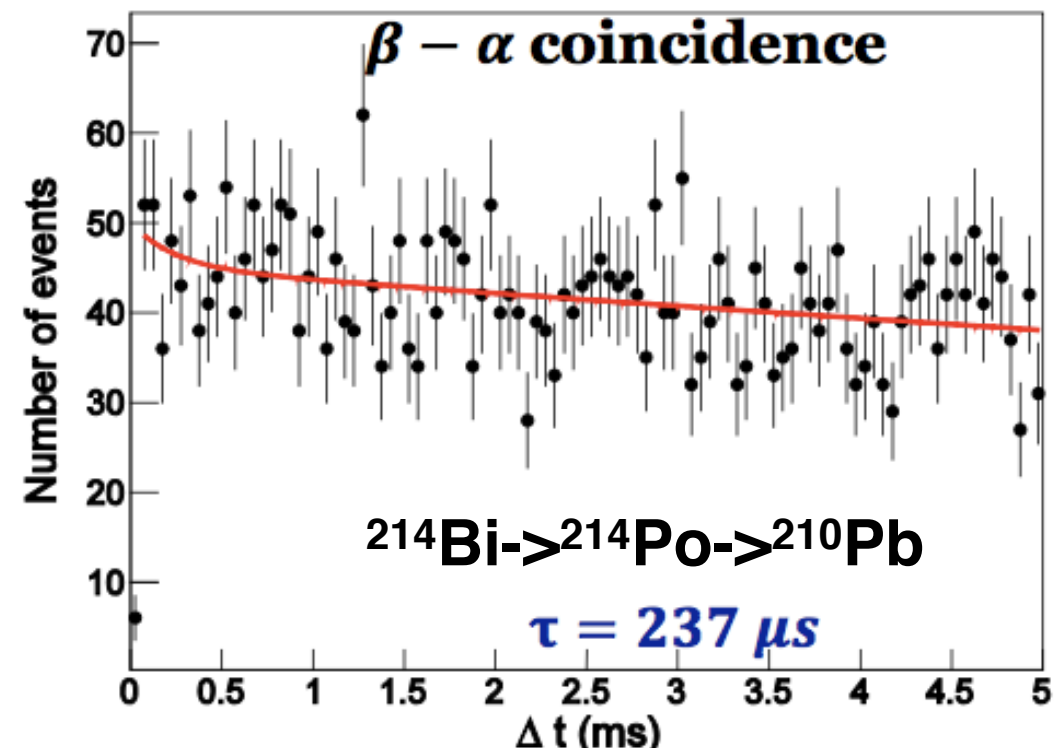


Backgrounds from ^{238}U and ^{232}Th are small

^{232}Th chain



^{238}U chain

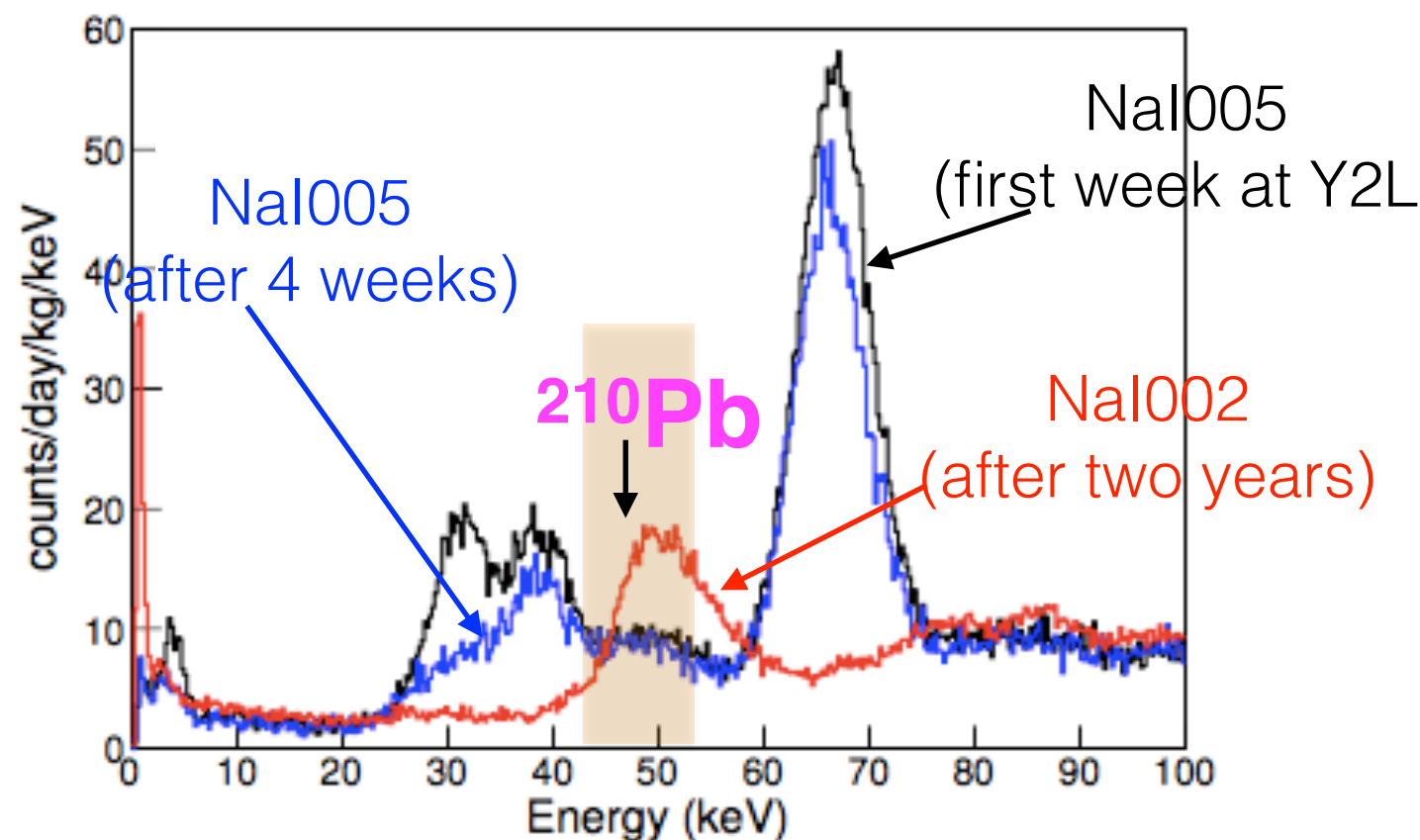


Internal Crystal Background (Alpha analysis)

DAMA : $^{210}\text{Pb}(\text{mBq/kg})=0.005\sim0.03$

	Nal-001	Nal-002	Nal-003	Nal-004	Nal-005	Nal-006
Total Alpha (mBq/kg)	3.29 ± 0.01	1.77 ± 0.01	2.43 ± 0.01	-	0.48 ± 0.004	1.53 ± 0.01
Powder	AS	AS	SA-AG	SA-CG	AS@	SA-CG

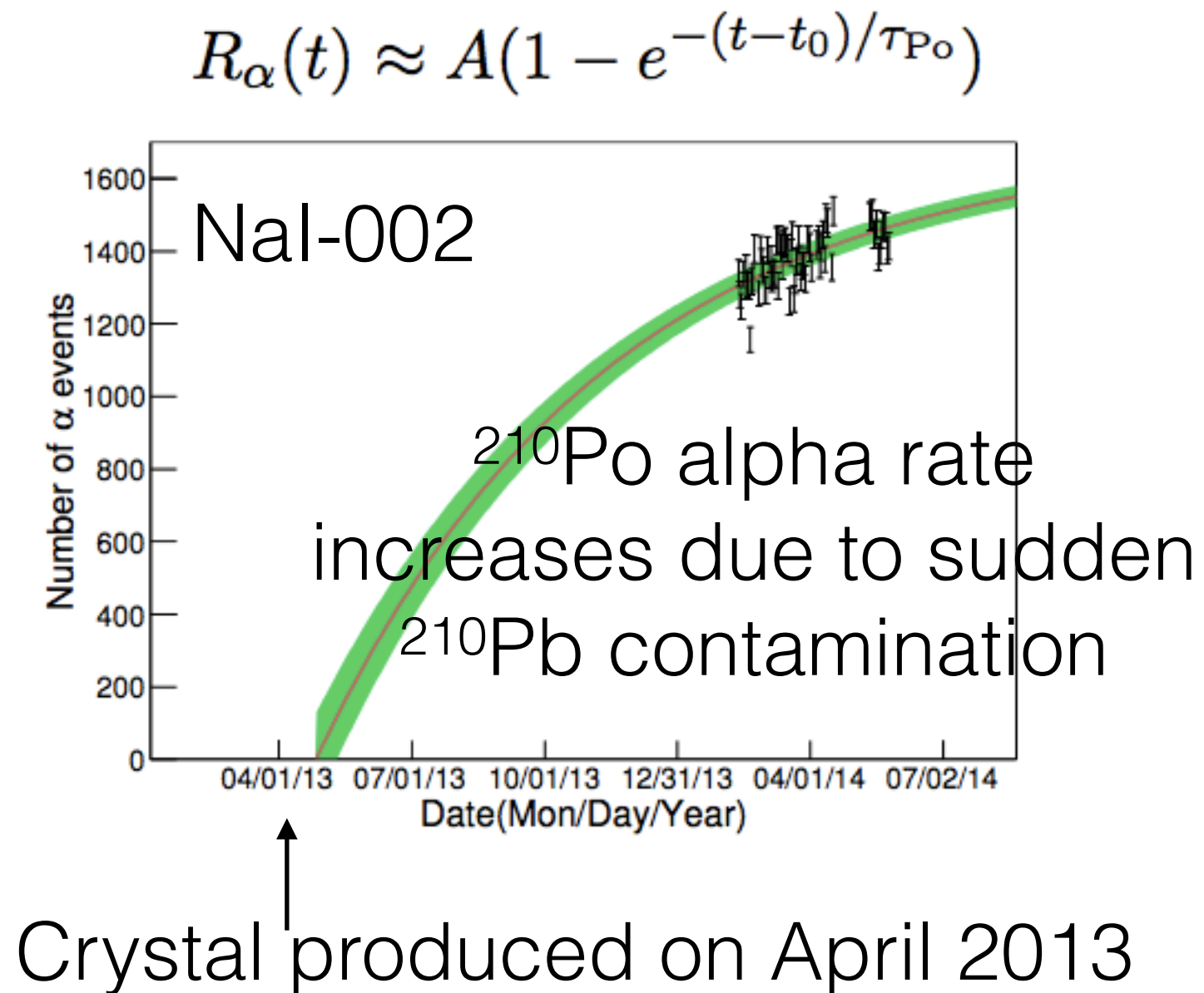
- Later crystals exposed less air (Rn) in growing process
- Nal-005 had a better treatment of chemical process on powder



Internal Crystal Background (Alpha analysis)

- Radioactive dating with alpha rate analysis

- Alpha analysis for ^{210}Po estimates ^{210}Pb contamination.
- The prediction coincides with the crystal growth date for all crystals
- Need to understand how ^{210}Po (^{210}Pb) was contaminated
 - Powder purification
 - Measurement for the powder



Internal Crystal Background (Pb Purification R&D)

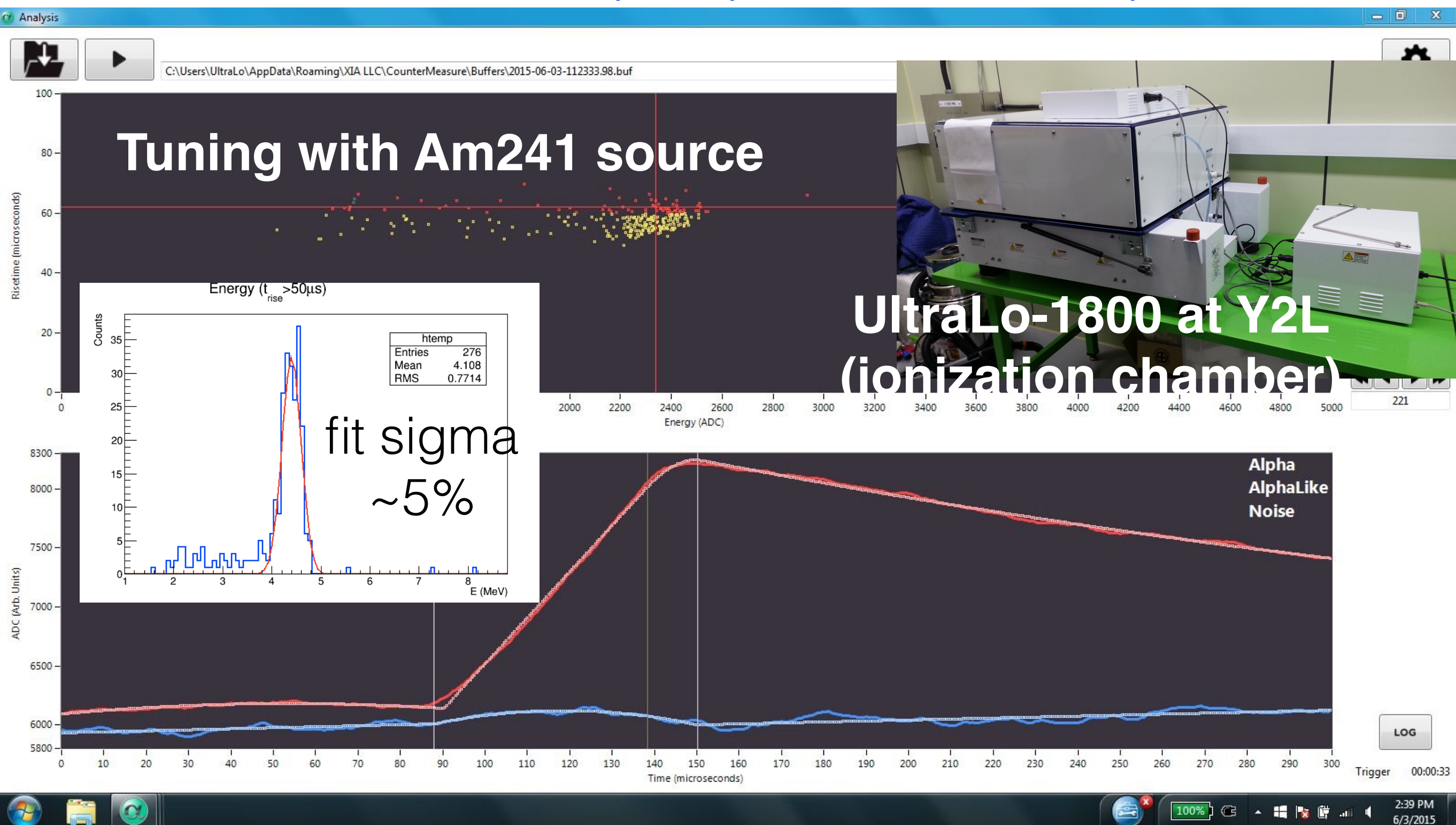
- NaI solution prepared with K and Pb artificially added
- **24h simple shaking applied with various resins**
- Encouraging results for Pb
- **Column chromatography (new) is under development.**



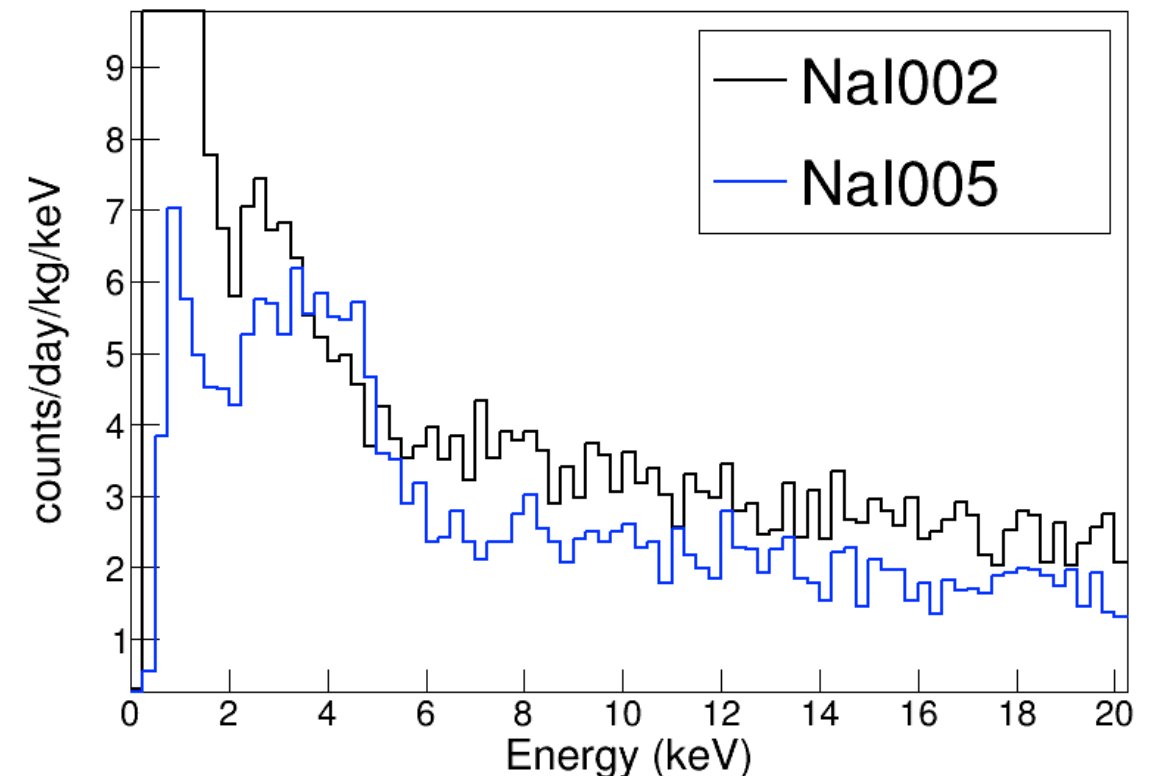
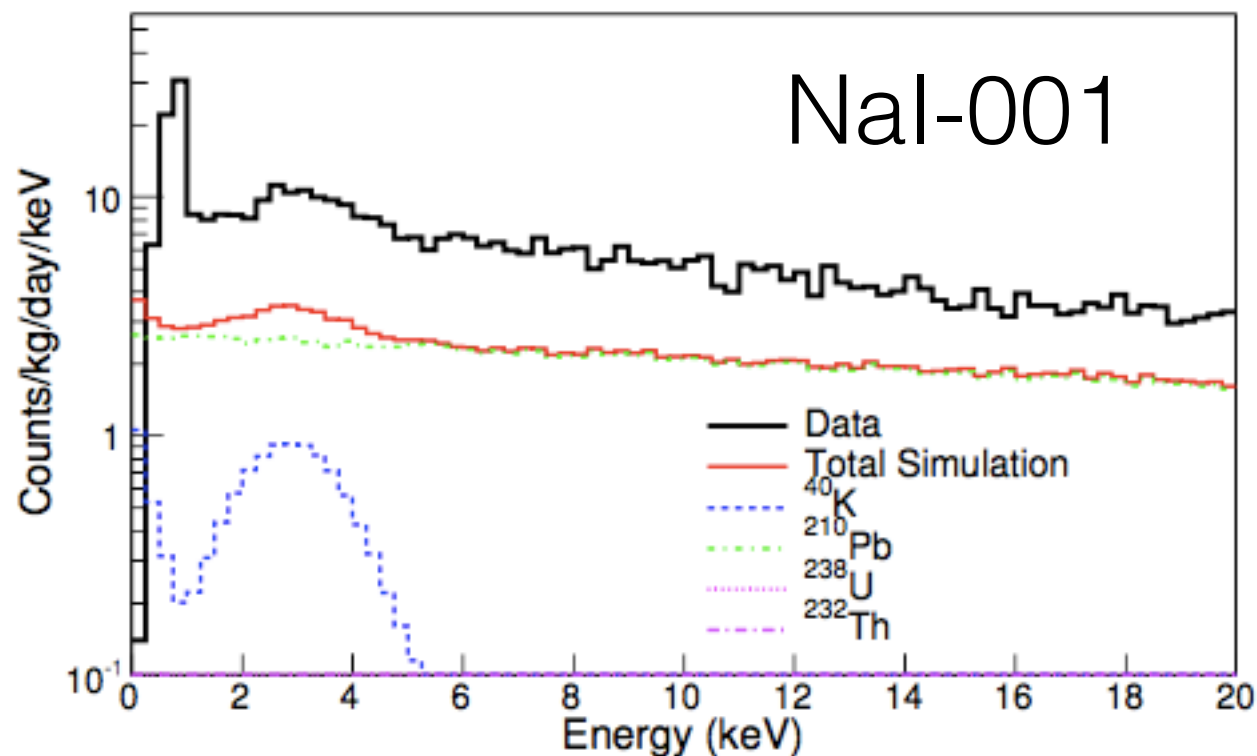
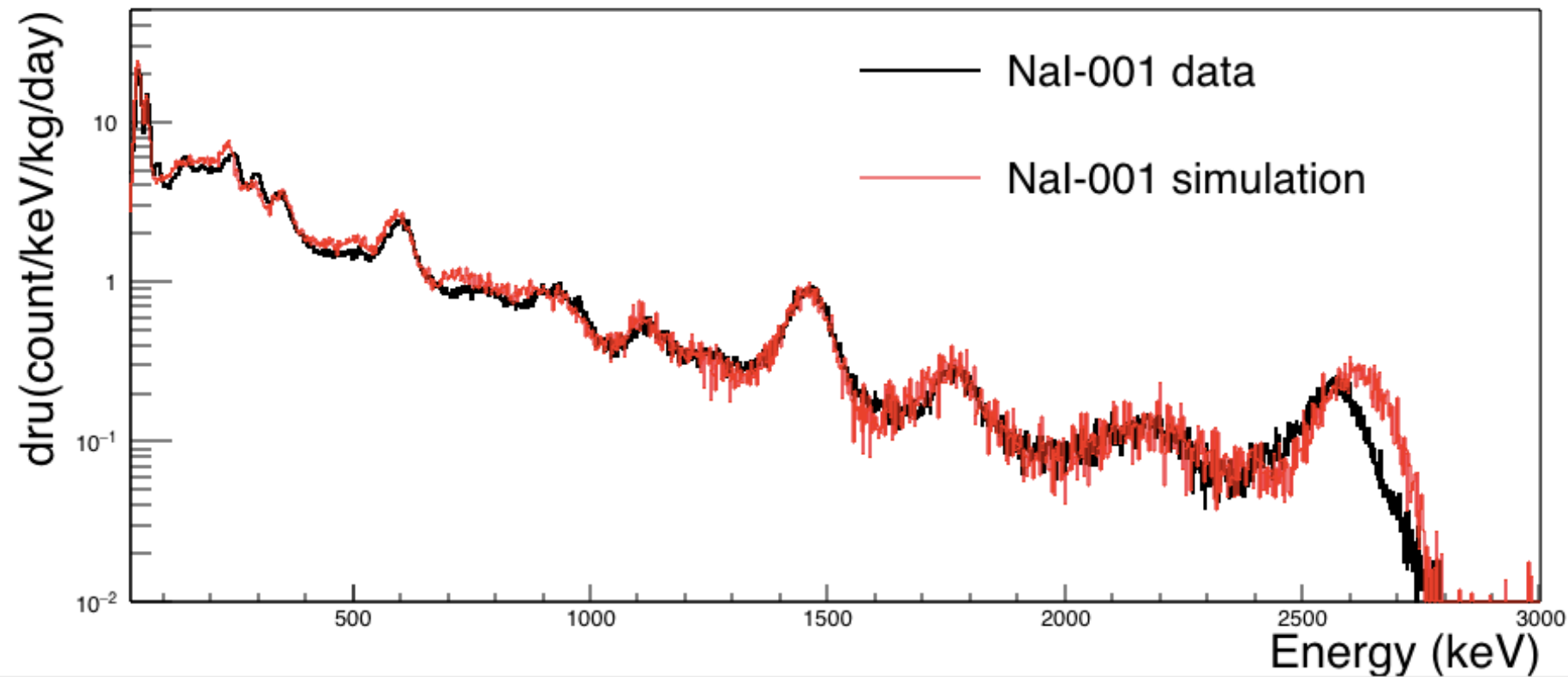
Sorbent	Matrix	Application	Resins	³⁹ K (ppb)			²⁰⁸ Pb (ppb)		
A	Inorganic, manganese dioxide	K ⁺ , Pb ²⁺		Bef.	Aft.	DF	Bef.	Aft.	DF
B	Inorganic, zinc ferrocyanide	K ⁺	A	223	254	0.9	1275	19	67
C	Organic macroporous anion exchange copolymer	Pb ²⁺	B	463	375	1.2	1693	1589	1.1
			C	404	313	1.3	1653	5	330

Without artificial contamination, preliminary results show about x3 reduction for Pb is possible.

Internal Crystal Background : Alpha counter (Plan to measure alpha particles in NaI powder)

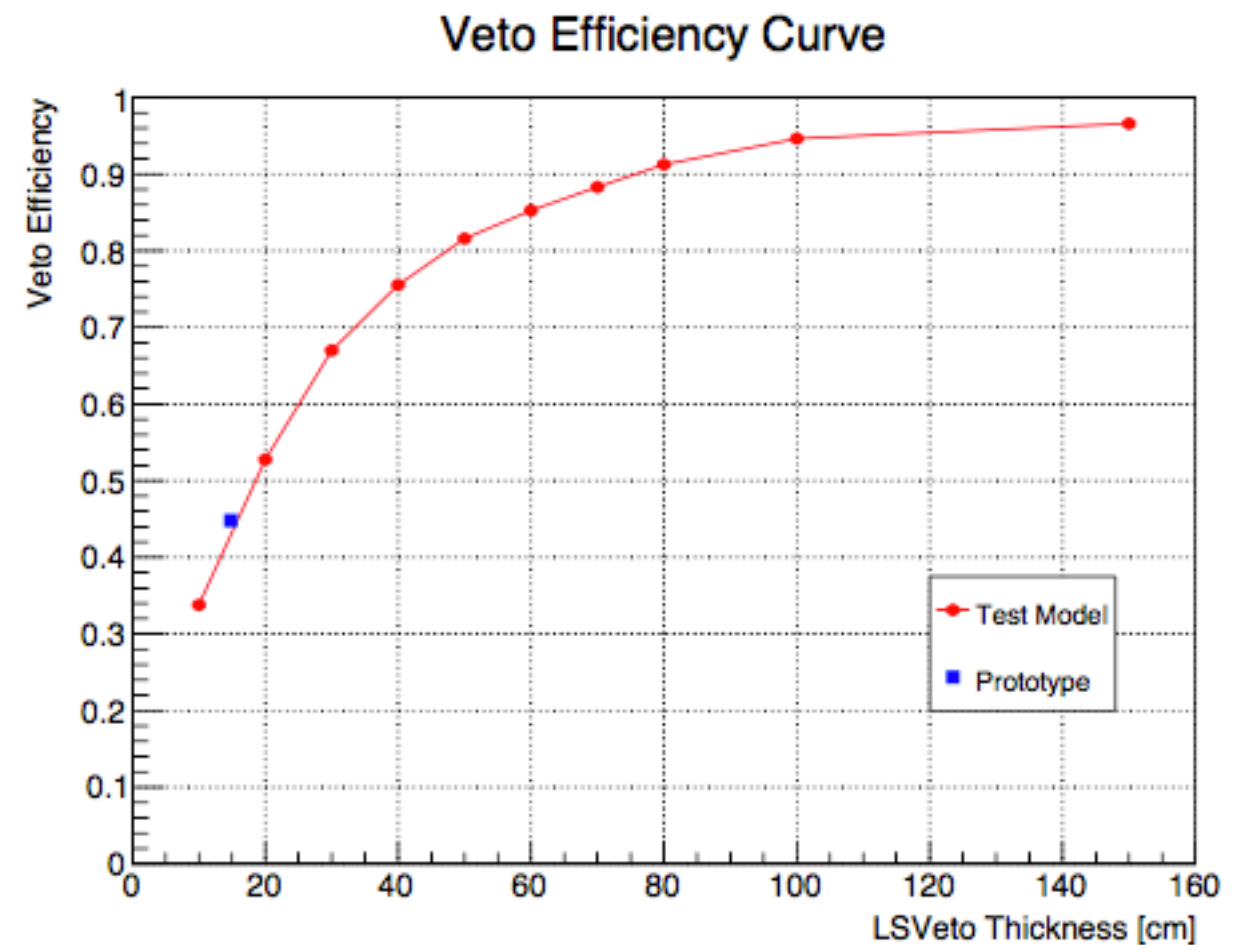
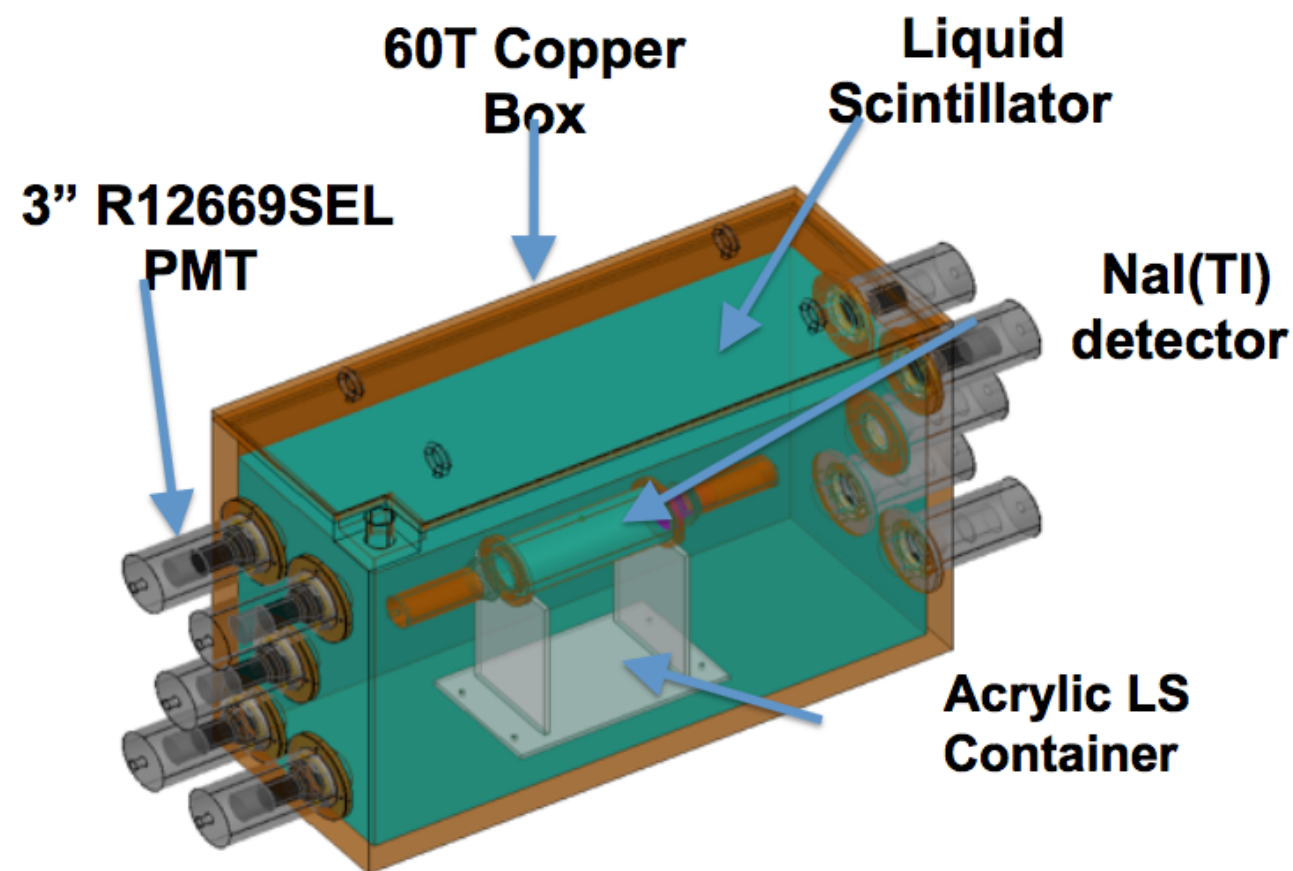


Energy Spectrum of crystals



More Background Reduction

-Liquid Scintillator Veto test setup



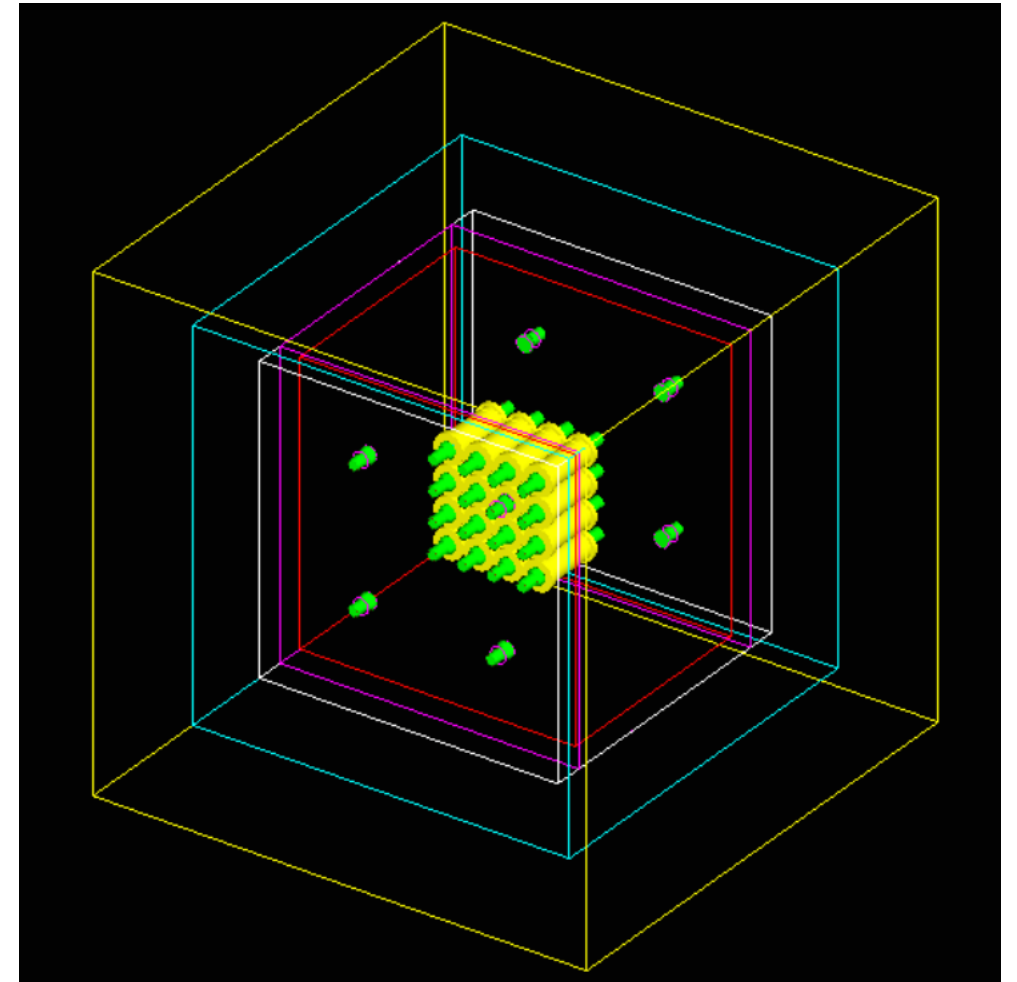
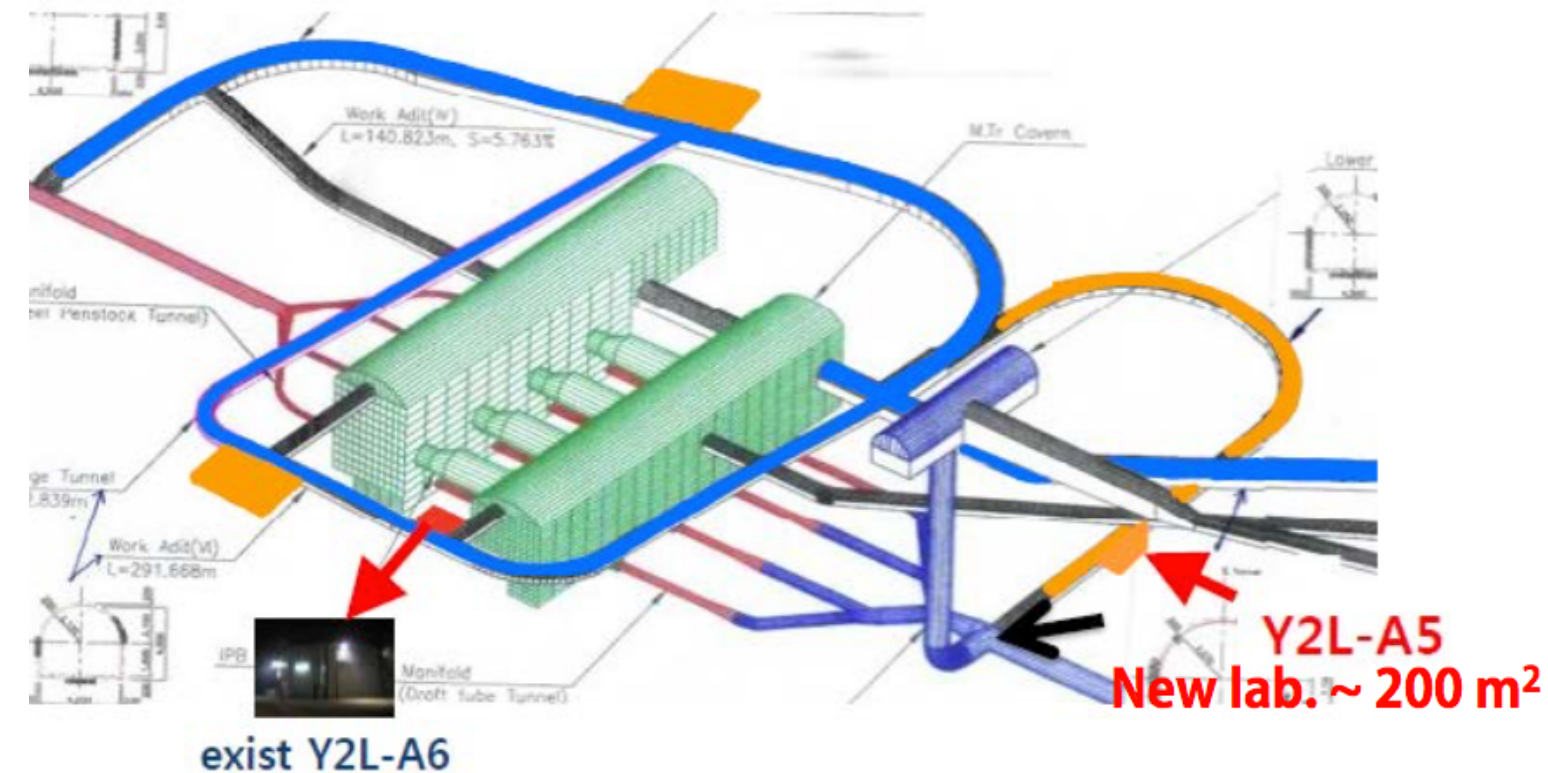
Additional reduction (70-80%) for backgrounds from U/Th/K with moderate veto thickness of 30-40cm

KIMS-NaI Preparation

-Aim at <1 dru in 200 kg NaI(Tl)

- **^{40}K : expected at ~ 0.1 dru (2-4 keV)**
 - ~ 10 ppb level crystal (grown from Sigma-Aldrich AstroGrade powder) is expected to arrive soon
 - Additional reduction from liquid scintillator veto
- **^{210}Pb : expected at 0.2 mBq/kg**
 - Currently at around 0.5 mBq/kg
 - Additional reduction expected from purification (expected 0.25 dru at 2 keV)
- **External + Cosmogenic : expected at less than 0.5 dru (veto)**

KIMS-NaI Site



200 kg NaI (TI) crystals
30 cm active LS veto
6 cm Cu
20 cm Pb (Gamma)
3 cm Plastic Scintillator (Muon)
30 cm Polyethylene (Neutron)

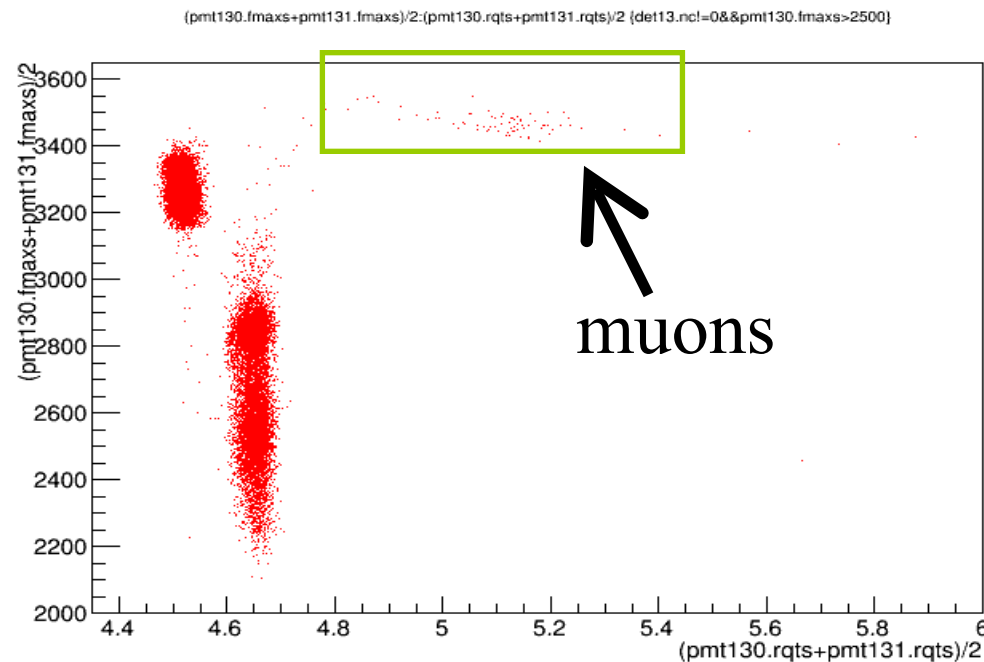
Conclusion

- Six NaI(Tl) crystals are evaluated at Y2L for KIMS-NaI 200 kg experiment
- Various R&D programs identified background reduction methods for ultra-pure crystal production.
- Current background level at 6 keV is ~ 2 dru.
- The level is expected to reach ~ 1 dru at around 2 keV and then, KIMS-NaI will soon start data-taking.

Backup

A substantial fraction of the remnant energy appears on a much longer time scale as a kind of phosphorescence, on time scales of minutes, hours, or even days.-Nygren

Muons are selected by amplitude-weighted mean time and energy distribution, and the time difference between muons and the following low energy events are obtained



- The low energy events following muons passing through the crystal didn't show peculiar timing distribution up to 300 seconds.
- Will analyze more data and up to 1 hr in time difference.

Low energy events : $0.5 \text{ keV} \leq E < 10 \text{ keV}$

